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METHODS FOR MAKING HIGHWAY SOIL SURVEYS

By K. B. Woods, M. ASCE

SURVEYING AND MAPPING DIVISION

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PAPERS

METHOD FOR MAKING HIGHWAY SOIL SURVEYS

By K. B. Woods,[1] M. ASCE

Synopsis

Rapid developments in the field of soil mechanics since about 1927, combined with improvements in the methods of design of bases and pavements, have led to important developments and refinements in methods for making highway soil surveys.

Established procedures for making these surveys include the use of test pits, core drilling, and auger borings to obtain samples for the determination of the engineering characteristics of the materials in the various layers and horizons of the soil profile. These procedures are costly, tedious, and somewhat slow. As a result, the engineer has been interested in refining these procedures and in developing new methods for making soil surveys.

Rapid advancements have been made in the use of agricultural soil-survey maps and certain types of geologic maps for soils engineering purposes. Methods of interpreting this information have enhanced the value of these maps for use in many sections of the United States. The development of airphoto interpretation techniques for bounding areas of soils of like engineering characteristics and for making engineering soil maps has led to the rather wide use of this tool. Resistivity methods and seismic methods for locating buried channels and for obtaining information on the depth of rock under a soil cover have had increased use, particularly in the New England states.

Introduction

For many years, highway engineers have used various procedures for obtaining information concerning the soils encountered in construction projects.[2,3]

Note.—Written comments are invited for publication; the last discussion should be submitted by **Mar. 1, 1953.**

[1] Associate Director, Joint Highway Research Project, and Prof. of Highway Eng., Purdue Univ., Lafayette, Ind.

[2] "Soil Surveys for Highways in New Hampshire," by J. O. Norton, *Engineering News-Record*, Vol. 114, 1935, pp. 706–709.

[3] "Soil Survey Practice in the United States," by Levi Muir and William F. Hughes, *Proceedings*, Highway Research Board, National Research Council, Vol. 19, 1939, pp. 467–483.

Increased use of highways by both passenger cars and trucks has created a need for better alinement, flatter grades, and wider and thicker pavements and base courses. These changes, in turn, have emphasized soil problems in drainage, foundations for embankments, landslides, and subgrade effects such as frost action and pavement pumping. The solution to most of these problems requires complete information on the engineering characteristics of the soils that are to be encountered during the construction process.

Some highway departments, including those of North Carolina, Missouri, and particularly Michigan, have used agricultural soil-survey techniques to develop soils maps for highway engineering use. The fact that these states continued to use these methods in lieu of more recently-developed ones attests to the soundness of the procedures. The slowness of other states to "borrow" from the related science of agriculture is probably caused, in part, by the complicated terminology used and by the lack of understanding of the concepts of pedology.

Geologic maps have long been of great value in many highway departments, particularly where the soil cover over rock is relatively shallow and the bedrock itself is the major material. Certain types of glacial maps have proved exceptionally useful for the compilation of general soils information, whereas new procedures in geologic mapping bear promise of contributing to that phase of soil mechanics concerned with the engineering characteristics of the immediate surface materials.

The aerial photograph is a more recent tool, used by highway engineers for obtaining information on soils. This technique has three direct uses—(*a*) in conjunction with field surveys for making large-scale engineering soil maps on a county basis or even on a state basis, (*b*) in gathering information concerning relatively unmapped areas through the fundamental principles of airphoto interpretation, and (*c*) in obtaining boundary information on materials of unlike characteristics and thus provide a method for predetermining the places where field data should be obtained.

Seismic methods and resistivity methods have not been universally accepted by highway engineers, although their use in the New England states has increased. However, these techniques have possible application in certain types of foundation problems and particularly in determining the elevation of bedrock buried under deep soil cover such as drift and wind-blown silt.

Highway Soil-Survey And Mapping Techniques

The purpose of the highway soil survey is to furnish information on the engineering characteristics of soils and rocks, for use by the design engineer in (*a*) the establishment of the final location of the road—both grade and alinement; (*b*) the selection of fill materials that will have optimum usefulness in embankments and subgrades; (*c*) the obtaining of subgrade information with respect to drainage requirements, possible frost action, the pumping of rigid pavements, and the rutting of flexible pavements; and (*d*) the location

of borrow material and of granular material for possible use as sub-bases and bases. [4,5,6]

The standard method used in developing information for the highway soil surveys includes the auger boring and test pits to determine the soil profile.[7,8] Particular attention is directed to the location of water-bearing strata. Samples are obtained that give information on texture, color, soil structure, consistency, compactness, cementation, and—in many situations—chemical composition. In the latter instance, emphasis is placed on the determination of organic matter and salts of the alkalies, and horizons with lime carbonate accumulations. In situations where foundations must carry heavy embankment loads, test pits are frequently used to obtain undisturbed samples for use in determining consolidation, shear, and permeability characteristics. Core drilling is common in bedrock country.

In almost all situations some field work is desirable. However, there is hardly a spot on the surface of the earth that has not been described sufficiently to afford some information on the character of the soil. The accuracy will vary, of course, but important data can usually be developed by a careful search of the existing information. Some of the most important material to be checked are geologic, pedologic, and topographic maps and aerial photographs.

Use of Geologic Maps for Highway Soil-Survey Purposes.—Utilization of geologic maps to assist the engineering soil surveyor depends greatly on the type of terrain involved and on the orignal purpose assigned to the development of the geologic map. In terrain where the overburden is shallow and residual soils have been developed from bedrock in place, the engineer will frequently find that geologic maps are almost indispensable for the economical collection of engineering data for a given road project.

For those who have an interest in working with generalized information, the 1933 edition of the Geological Map of the United States, published by the United States Geological Survey (USGS), is recommended. This map has some use for regional planning and for an over-all understanding of the bedrock geology of the United States. Its limitations with regard to soil-survey work include (*a*) an almost complete lack of information on glacial deposits and loessial deposits, and (*b*) a geolgoic time concept in place of a rock-texture concept. Most of the states of the United States have "geologic surveys" and through these facilities, or through the facilities of the USGS, geological maps of individual states are frequently available. Of course, such maps are more useful than the Geological Map of the United States because of their increased scale, but their limitations when used for engineering work are similar to those of the USGS map.

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[4] "Classification and Identification of Soils," by Arthur Casagrande, *Transactions*, ASCE, Vol. 113, 1948, p. 901.

[5] "Report of Committee on Classification of Materials for Subgrades and Granular Type Roads," *Proceedings*, Highway Research Board, National Research Council, Vol. 25, 1945, pp. 375–392.

[6] "Standard Methods of Surveying and Sampling Soils for Highway Subgrades," A.A.S.H.O. Designation: T 86–42, *Highway Materials*, Part II, Tests, Am. Assn. of State Highway Officials, 1947, p. 178.

[7] "Soil Mechanics Applied to Highway Engineering in Ohio," by K. B. Woods and R. R. Litehiser, *Engineering Bulletin No. 99*, Ohio State Univ., Columbus, Ohio, Vol. 7, No. 2, July, 1938.

[8] "Subgrade Soil Practices," by Tilton E. Shelburne, from "Report of Committee on Concrete Pavement Design," *Technical Bulletin No. 121*, Am. Road Builders' Assn., 1947, pp. 3–27.

Geologic reports and accompanying maps, made on a quadrangle basis, or even on a county basis, are useful for highway soil-survey purposes. Such reports and maps usually contain detailed information about bedrock and all surficial deposits.[9,10,11] Geologic reports and maps of this type include rather detailed information on the nature of terrace deposits and the textures of upland soils; and emphasis is placed on the location and engineering characteristics of select materials of construction. The ultimate potential of this type of geologic presentation has not been fully realized, not only in highway engineering but also in airport work, site selection, ground-water study, and general engineering.

A third type of geologic presentation is the report (accompanied by maps) that is frequently available for glacial areas. The glacial maps of Maine,[12] Minnesota,[13] and other states are well done and they have wide application for engineering soil-survey purposes. The terminology is different from that used by the engineer and some effort must be devoted to obtaining background with respect to the methods employed in mapping and to the terminology used. Such terms as "kames," "eskers," "drumlins," "outwash plains," "till plains," "moraines," and "lacustrine deposits" are the word tools used by the geologist in presenting his information concerning glacial areas.

Use of Agricultural Soil-Survey Maps.—Procedures for making agricultural soil maps have been evolved during the 50 years or more since the beginning of the century. The oldest maps contain boundary information similar, in many respects, to certain types of geologic boundaries. Over a 25-year period (since about 1927) these procedures have been refined to include the climatic aspects of soil development as one of the major variables. Constant research and many years of experience have enabled the pedologist to improve his mapping procedures so that the modern soil-survey map includes not only parent material and climate as variables, but also vegetation, slope, and age of the material.[14]

Because these maps are prepared on a local political boundary basis—a county basis, for instance—it is frequently true that the variations of climate, parent material, vegetation, and length of the weathering time within the given political unit are either insignificant or their influence on the soil properties cannot be determined within the limits of the one map. This leaves topography as the major variable. The nomenclature used to designate the various soils includes geographical names that refer to the type of locality where the soil was first mapped. Soils differing primarily in slope variations are grouped together as a "catena." Descriptions of various horizons or

[9] "Geology and Mineral Resources of the Cleveland District, Ohio," by H. P. Cushing, Frank Leverett, and Frank R. Van Horn, *Geological Survey Bulletin 818*, U. S. Dept. of the Interior, 1931.

[10] "Maps of Construction Materials," by Frank E. Byrne, from "Soil Exploration and Mapping," *Bulletin No. 28*, Highway Research Board, National Research Council, 1950, p. 63.

[11] "Preparation of an Engineering Geologic Map of the Homestead Quadrangle, Montana," by Clifford A. Kaye, from "The Appraisal of Terrain Conditions for Highway Engineering Purposes," *Bulletin No. 13*, Highway Research Board, National Research Council, 1948, p. 48.

[12] "A Survey of Road Materials and Glacial Geology of Maine," by H. Walter Leavitt and Edward H. Perkins, *Bulletin No. 30*, Vol. II, Maine Technology Experiment Station, Orono, Maine, 1935.

[13] "Quaternary Geology of Minnesota and Parts of Adjacent States," by Frank Leverett and Frederick W. Gardeson, *Professional Paper No. 161*, U. S. Geological Survey, Washington, D. C., 1932.

[14] "Soils of the United States," by C. F. Marbut, from "Atlas of American Agriculture," Part III, Bureau of Chemistry and Soils, USDA (Advance Sheets, No. 8), July, 1935.

layers of the soil profile include detailed information such as the color, texture, structure, and compactness. Unfortunately, actual laboratory tests have not been reported extensively and the reader must obtain his knowledge of the soils from the word picture developed in the report accompanying the soil-survey map.

Most of the information shown on the agricultural soil-survey map can be used for engineering soil-survey purposes.[15,16] However, the information presented on these maps is frequently given in considerable detail; thus it is often desirable to regroup the soils shown on the agricultural soil map in the construction of the engineering soil map.

The pedological method of soil survey has been utilized in two general ways. In states such as Michigan,[17] Missouri,[18] and North Carolina the soil-survey terminology is used with very little change by the soils engineer and any new maps that must be prepared for a given highway project embody the basic principles used by the pedologist in the preparation of this soil-survey map. In Michigan (for example), the soils engineer who prepares the soils map for the location survey aids in the preparation of plans and specifications and makes field inspections during the construction period. In contrast, states such as New York,[19] Indiana,[20] and many others use the available agricultural soil-survey maps for determining the general characteristics of the area in question and for locating important areas for field sampling. These data are then supplemented by actual laboratory tests on carefully selected soil samples. Both field and laboratory work can be reduced materially by the employment of either of these two processes.

Seismic and Electrical Resistivity Methods.—Since the early 1930's, the United States Bureau of Public Roads and some state highway departments have experimented with geophysical methods of subsurface exploration.[21] R. Woodward Moore and E. Raymond Shepard have published much information concerning these methods.[22,23]

The seismic procedure consists of creating waves by exploding small charges of dynamite buried near the surface of the soil and "measuring the time of travel of these waves from their point of origin to each of several detectors placed at small distances from the source".[22] The mechanical energy picked

[15] "Longitudinal Cracking of Concrete Pavements on State Highway 12 in Clark and Taylor Counties, Wisconsin," by H. F. Janda, *Proceedings*, Highway Research Board, National Research Council, Vol. 15, 1935, pp. 157–169.

[16] "Engineering Use of Agricultural Soil Maps," *Bulletin No. 22*, Highway Research Board, National Research Council, 1949.

[17] "Field Manual of Soil Engineering," Michigan State Highway Dept., Lansing, Mich., February, 1946.

[18] "Soils Manual," Missouri State Highway Comm., Bureau of Materials, Jefferson City, Mo., 1948.

[19] "An Engineering Grouping of New York State Soils: Geology of New York, Engineering Grouping of Soils, Production of Area Soil Maps, Use of Engineering Soil Maps," by Earl F. Bennett and George W. McAlpin, from "The Appraisal of Terrain Conditions for Highway Engineering Purposes," *Bulletin No. 13*, Highway Research Board, National Research Council, 1948, pp. 55–63.

[20] "Distribution, Formation, and Engineering Characteristics of Soils," by D. J. Belcher, L. E. Gregg, and K. B. Woods *Engineering Bulletin*, Purdue Univ., Lafayette, Ind., *Research Series No. 87*, Vol. 27, January, 1943.

[21] "Application of Geology and Seismology to Highway Location and Design in Massachusetts," from "The Appraisal of Terrain Conditions for Highway Engineering Purposes," *Bulletin No. 13*, Highway Research Board, National Research Council, 1948, pp. 66–90.

[22] "Development of Geophysical Methods of Subsurface Exploration in the Field of Highway Construction," by R. Woodward Moore, from "Soil Exploration and Mapping," *Bulletin No. 28*, Highway Research Board, National Research Council, 1950, p. 73.

[23] "Subsurface Explorations by Geophysical Methods," by E. Raymond Shepard, *Proceedings*, A.S.T.M, Vol. 49, 1949, pp. 993–1009.

up by the detectors is converted into electrical energy and a record is made of the time required for the wave to be transmitted from its source to any given pickup. An analysis is made of the data thus collected at the several pickups, and predictions are made with respect to the nature and depth of the various layers of material. The method has particular application in finding rock lines under buried soils and in evaluating foundation problems, especially in peat bogs and in swampy areas.

In the electrical resistivity method, the resistance to the flow of an electric current through the subsurface materials is measured at certain intervals of the ground surface. Because many rocks and soils have differences in resistivities, it is often possible to develop a general idea of subsurface conditions. The method has particular application to geological work in bedrock areas. However, the method has been used for solving foundation problems, and particularly for finding rock lines under deep soil cover, for mapping buried channels, and for obtaining information on the characteristics of rock and soil materials in highway cut sections.

Use of Aerial Photographs in Soil Surveying.—In the late 1920's, aerial photographs were first used in the preparation of agricultural soil-survey maps.[24] All agricultural soil-survey maps in Indiana are now (1952) made with the aid of airphotos.

The adaptation of this technique to engineering soil surveys has been pursued at Purdue University, at Lafayette, Ind.,[20,25] and at other institutions. The aerial photograph has three distinct applications with respect to the highway soil survey. In the first place, the airphoto can be used advantageously for locating the boundaries between soils of unlike characteristics and from this information a generalized engineering soils map can be prepared.[26] Carefully planned field checks constitute an essential part of this type of program and the precision of airphoto interpretation depends upon the quantity of detail desired in the finished map. Secondly, the aerial photograph is used in unmapped areas, in particular, to predict the engineering characteristics of soils.[27] The processes involved in this type of work require considerable study and training on the part of the interpreter and moderately rigid photographic specifications must be used with respect to scale, quality of paper, and climatic influence at the time of flight. The third, and perhaps most practical, use of the aerial photograph is for locating field-sampling areas in connection with the development of the engineering soil-survey strip map for a given highway project.[28,29] These photographs, used either alone or in conjunction with

[24] "The Story of Indiana Soils," by T. M. Bushnell, *Special Circular 1*, Agri. Experiment Station, Purdue Univ., Lafayette, Ind., June, 1944.

[25] "The Origin, Distribution and Airphoto Identification of United States Soils," by D. S. Jenkins, D. J. Belcher, L. E. Gregg, and K. B. Woods, *Technical Development Report No. 52*, Civ. Aeronautics Administration, May, 1946.

[26] "The Engineering Significance of Airphoto Patterns of Northern Indiana Soils," by Pacifico Montano, thesis presented to Purdue University at Lafayette, Ind., in June, 1946, in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering.

[27] "The Development of Engineering Soils Maps," by D. J. Belcher, *Proceedings*, Twenty-ninth Annual Purdue Road School, *Engineering Bulletin*, Purdue Univ., Lafayette, Ind., *Extension Series No. 55*, Vol. 27, No. 2, March, 1943, pp. 86–92.

[28] "The Use of Aerial Maps in Soil Studies and in the Location of Borrow Pits," by R. E. Frost, *Proceedings*, Kansas State Highway Eng. Conference, July 1, 1946, pp. 58–82.

[29] "Airphoto Interpretation of Soils and Drainage of Parke County, Indiana," by Merle Parvis, thesis presented to Purdue University at Lafayette, Ind., in June, 1946, in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering.

geologic, pedologic, or even topographic maps, have wide application in this type of survey. The Sonne, strip-film method (low altitude, continuous strip) has possibilities, not only for soil survey but also for use in pavement performance surveys, in topographic and property line surveying, and even for location work.[30]

Regardless of the intended use of the aerial photograph in connection with the soil-survey work, it is important that the soils engineer have some general background in the methods involved. He should have a good concept of pedological and geological methods of mapping, including the basic concepts

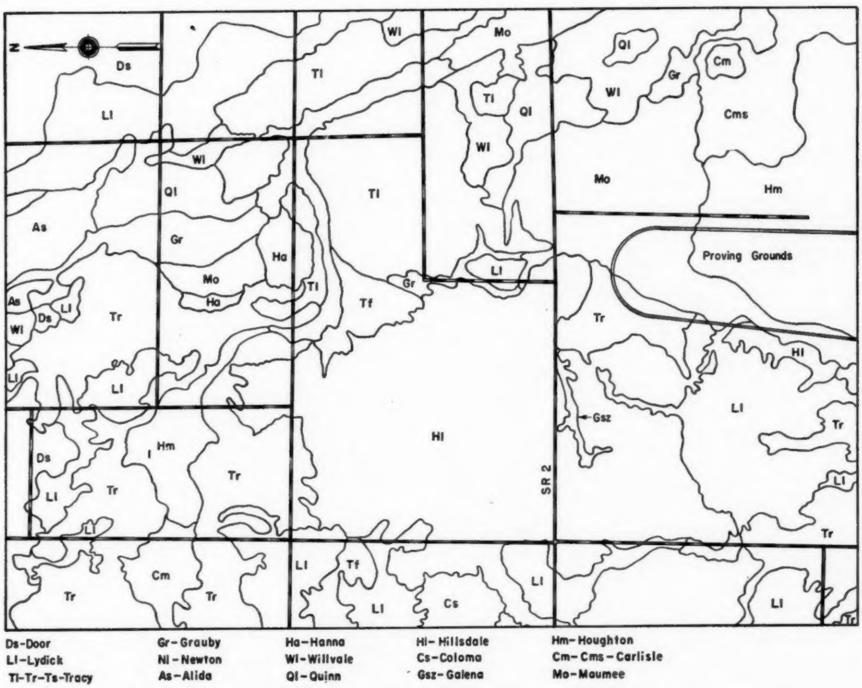

FIG. 1.—PART OF AN AGRICULTURAL SOIL-SURVEY MAP OF ST. JOSEPH COUNTY, INDIANA

from which these sciences have been developed; and he should have some background in airphoto interpretation techniques.

Through research, airphoto interpretation techniques have been developed that have resulted in the definition of certain so-called "elements of the pattern."[31] These elements include the "landform" or "topographic expression," the "drainage pattern," the "color tones," "erosional characteristics," and "land use." Of all these elements, perhaps the most important with respect to the identification of the textures of soil and rock materials is that of the

[30] "Application of Aerial Strip Photography to Highway and Airport Engineering," by J. E. Hittle, *Proceedings*, Highway Research Board, National Research Council, Vol. 26, 1946, pp. 226–235.

[31] "Aerial Photographs Used for an Engineering Evaluation of Soil Materials," by R. E. Frost and K. B. Woods, *Proceedings*, Second International Conference on Soil Mechanics and Foundation Eng., Rotterdam, Holland, 1948, pp. 324–330.

topographic expression. Such glacial forms as kames, eskers, and terraces—which in turn suggest soil textures—are easily identified. In bedrock regions, the character of the rock can usually be predicted on the basis of certain landform elements. For example, flat-lying soluble limestones contain sinkholes; and alternate beds of shale and sandstone, outcropping in a tilted position, appear in the airphoto as valleys and ridges.

Drainage and erosional features are important elements of the airphoto pattern. In shale areas, for example, channels and gullies meander considerably because of the softness of the bedrock material. Tilted rocks produce trellis-like drainage, and in alternating layers of hard and soft rocks the major streams usually flow in valleys that have been developed in the soft rocks.

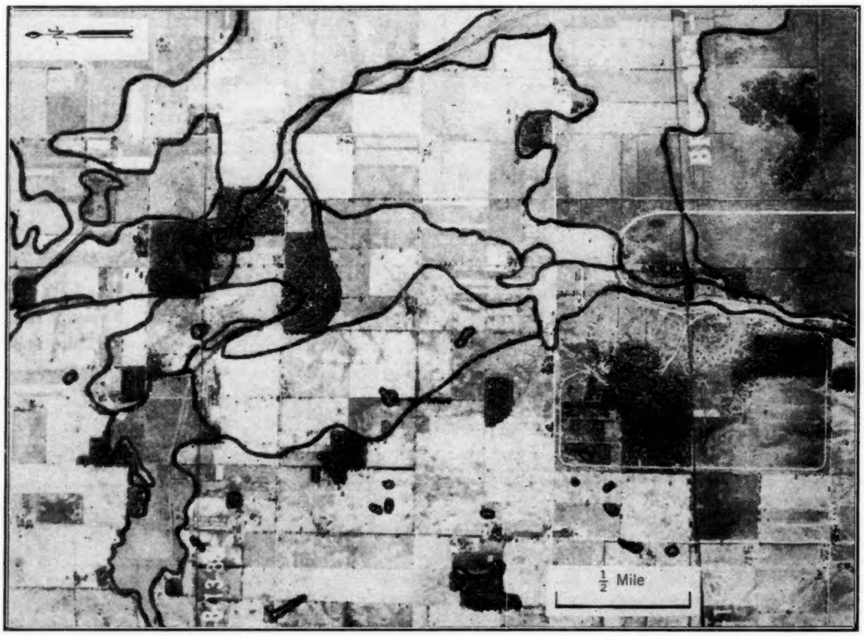

Fig. 2.—Contact Aerial Photograph of Area Shown in Fig. 1.

Important data can usually be obtained by a study of the gullies. Each abrupt change in cross section, direction, or grade is accompanied by a change in soil profile or in rock strata. Deep uniform soils have deep but uniform gully gradients and similarities of gully cross sections. Short **V**-shaped gullies with steep gradients are characteristic of noncohesive soils whereas **U**-shaped gullies with short, steep gradients are indicative of deep uniform soils of silt texture. Rounded saucer-shaped gullies with low gradient are usually indicative of cohesive soils.

The true soil color is represented in the airphoto by shades of gray, ranging from black to white. In general, well-drained soils are represented in the photograph by soft, white colors, whereas dark-colored organic soils and clays

photograph black or in dark gray tones. Contrasting color tones in the photograph are usually indicative of changes in soil textures. However, the climate, topography, and vegetation may, in some instances, modify even these broad generalities.

Nationwide use of aerial photographs in soil-survey work was realized after a development period of less than 10 years. In a survey made by Robert D. Miles,[32] J. M. ASCE, it was determined that nineteen highway departments use aerial photographs for soils and drainage work, and that practically all highway departments use airphotos for some highway purpose. Airphotos have been used for site selection by the Civil Aeronautics Administration[20]

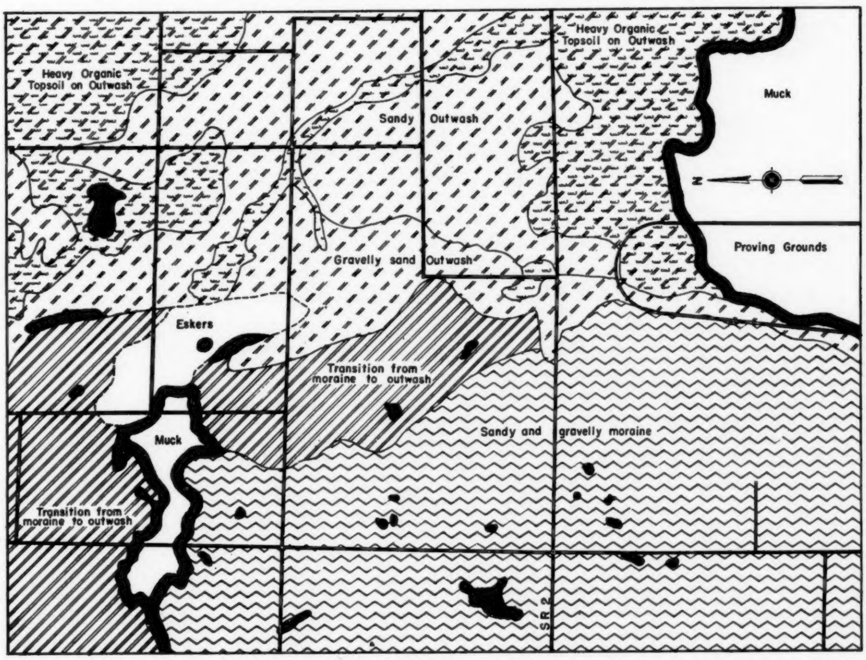

FIG. 3.—AN ENGINEERING SOILS MAP OF THE AREA SHOWN IN FIGS. 1 AND 2

and later by the Corps of Engineers, United States Department of the Army.[33] It seems safe to assume that this tool will find increased use as interpretation techniques are developed and as more soils engineers become familiar with these techniques.

Combined Use of Several Methods.—The modern highway soils engineer is finding that the most economical procedure to be followed in developing the highway soils survey is to utilize all the various types of maps and information

[32] "Procedures for Making Preliminary Soils and Drainage Surveys from Aerial Photographs," by Robert D. Miles, thesis presented to Purdue University at Lafayette, Ind., in June, 1951, in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering.

[33] "Correlation Between Permafrost and Soils as Indicated by Aerial Photographs," by K. B. Woods, Jean E. Hittle, and R. E. Frost, *Proceedings*, Second International Conference on Soil Mechanics and Foundation Eng., Rotterdam, Holland, 1948, pp. 321–324.

available.[34,35,36,37] These include topographic maps, agricultural soil-survey maps, various types of geologic maps, and contact airphoto prints. Illustrations of the combined use of various available maps are shown in Figs. 1, 2, and 3.

Fig. 1 represents a part of an agricultural soil-survey map from St. Joseph County, Indiana, in the glacial drift region. The nomenclature at the bottom of this figure indicates the typical method of naming soils. Fig. 2 is an aerial photograph made to approximately the same scale as the soil-survey map, and it was selected to cover approximately the same area. The boundary information shown is that which usually would be established for the development of a generalized engineering soils map. Fig. 3 shows the engineering soils map as interpreted from the aerial photograph and the agricultural soil-survey map.

Conclusion

Because geology, pedology, and airphotos offer a vast store of data to supplement and minimize the gathering of data for soil surveys, it is probable that in the future the larger soils sections of highway departments will employ not only engineers well versed in the field of soil mechanics, but also geologists, pedologists, and airphoto interpreters, in order that highway soil surveys can be produced in a minimum of time and at a reasonable cost. Specialists with the proper background and training are needed to help engineering organizations realize the full benefits from these sources of information.

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[34] "The Preparation of Engineering Soil Maps from Aerial Photographs," by Charles R. McCullough, *Proceedings*, Third Annual Florida Highway Conference, *Bulletin Series No. 31*, Vol. 4, No. 1, January, 1950, pp. 42–53.

[35] "Soils Manual," Wyoming Highway Dept., Soils Div., Cheyenne, Wyo., 1949.

[36] "State-Wide Highway Planning Survey Soil Study," *Bulletin No. 6*, State of Nebraska, Dept. of Roads and Irrig., Bureau of Roads and Bridges, 1939.

[37] "Soils of Iowa," *Special Report No. 3*, Iowa Agri. Experiment Station, Agronomy Section, Soils Subsection, November, 1936.